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Current Reset in Superconducting Devices

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1. Introduction

Many superconducting devices operate in persistent mode. MRI, NMR and some superconducting rotating machinery are examples of such systems. In order to minimize the operation heat losses, charging leads are either retracted (minimize conduction) or have permanent leads (optimized for minimum conduction losses). Persistent magnets require periodic current adjustment through the current leads when the current in the magnet decays over time. In addition, it might be advantageous to ramp the unit to zero current when there is a long-time power outage or system malfunction. The ramp and re-calibration require engagement of the current leads.

2. Retractable and Permanent Leads

- Retractable high-current leads (RHCL) are used in thousands of commercial MRI and NMR magnets. While reducing the conduction losses during operation in persistent mode, the retractable leads should address multiple challenges
- The permanent current leads, while reliable, do generate heat losses even at zero current, The minimum heat load generated in the leads during ramp is nearly independent of the material chosen but heat loads in steady state conditions after power supply removal still require a careful material selection. Brass is a good option.

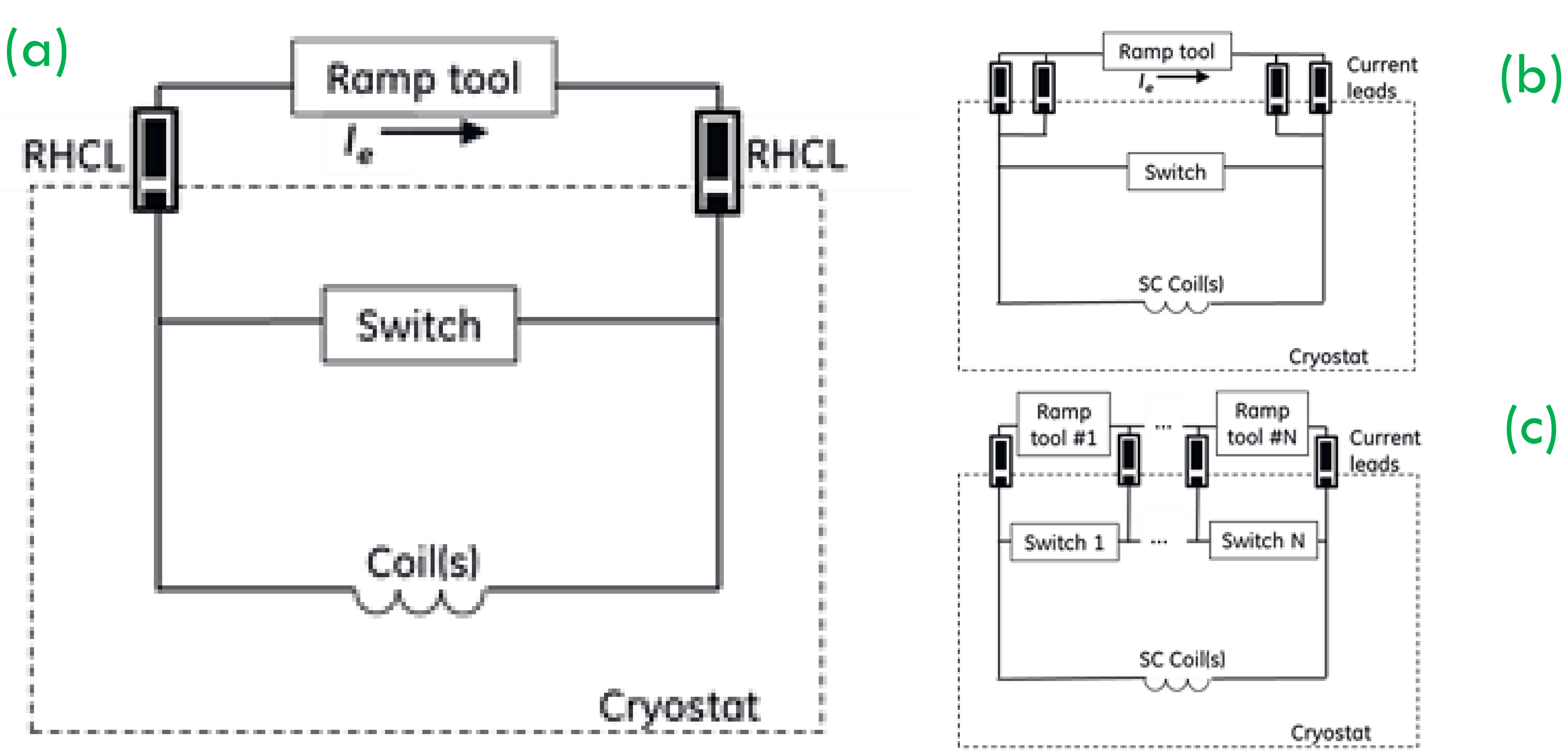

Figure 1. Magnet configurations with ramp lead redundancy for reliability.

Two different RHCL configurations are shown: reducing conduction heat load during persistent mode, but challenges are
- Require high contact pressure
- Maintain clean surface condition
- Ware and tear over time

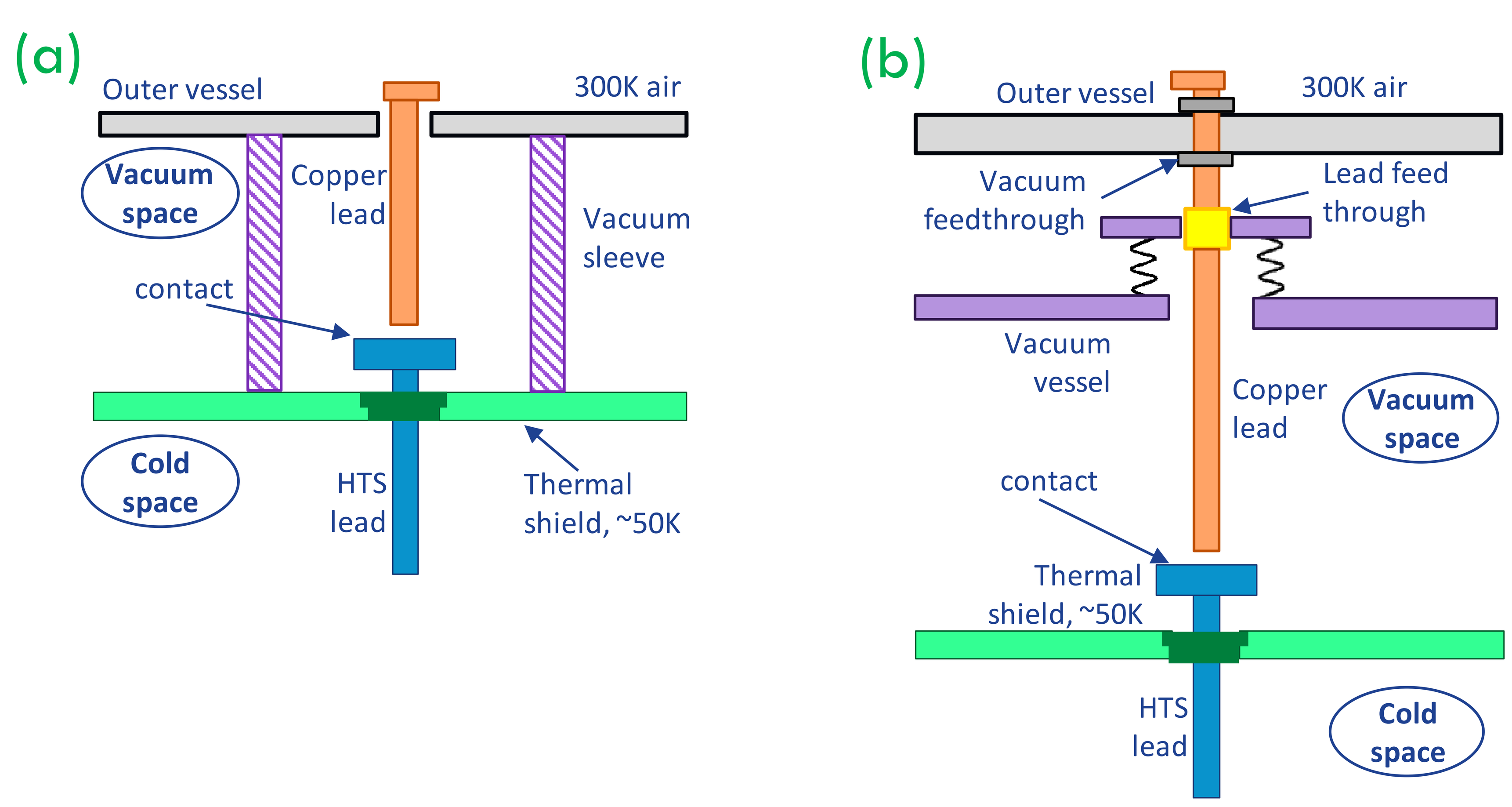

Figure 2 Illustration of two different RHCL configurations
(a) RHCL in a closed space not under vacuum. (b) RHCL in vacuum space

3. Flux pump for small current adjustment

In many applications, magnets require relatively small current adjustment. This is because some superconducting coils have small resistance, which will cause the current to decay slowly over time. The flux pump shown in Figure 3 with low-current charging leads, either retractable or permanent, will do the trick. A flux pump reduces the high heat load associated with high current leads, by using a pair of small current leads to supply current to a superconducting transformer, where the primary coil carries much lower current than the secondary coil that the main SC coil(s) needs

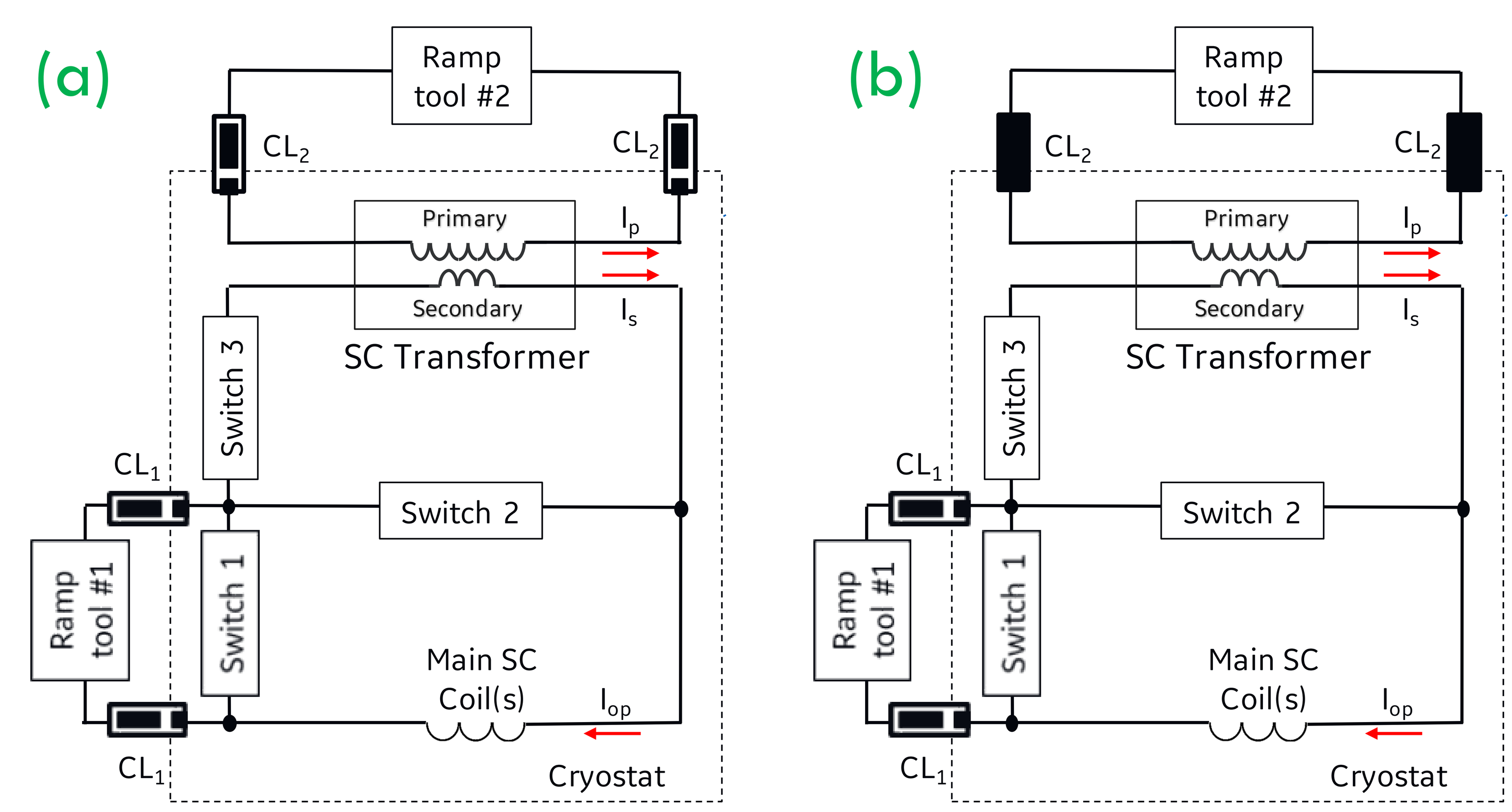

Figure 3. Schematics of a flux pump: (a) Retractable CL_2, (b) Permanent CL_2

Operating Procedures

(1) During a normal operation, S_2 and S_3 are closed. The main coil current I_{op} trickles down.
(2) Ramp up I_p through CL_2 to induce $I_s > I_{op0}$ in the secondary of the SC transformer.
(3) Open S_2 to pump energy to the main coil, by commutating I_s to I_{op0}.
(4) Close S_2 to isolate the main coil from the pump
(5) Ramp down I_p to zero ➔ $S_3 \sim 0$ and $S_2 \sim I_{op0}$, reducing S_3 heat dump, and increase S_2 stability.
(6) Open S_3 to discharge the pump circuit.
(7) Close S_3 to complete the pumping cycle.

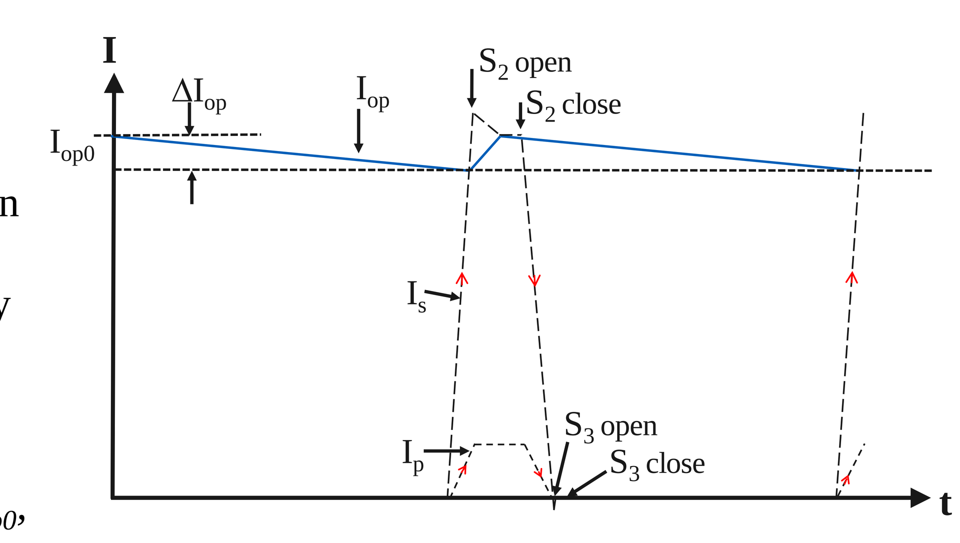

Figure 4. Illustration of main coil current and transformer current during one flux pump cycle

4. Remotely Controlled Features

To increase reliability and improve performance for remote operations over time by
- Adding heaters to leads to de-icing
- Using a polish tool to clean contact surface

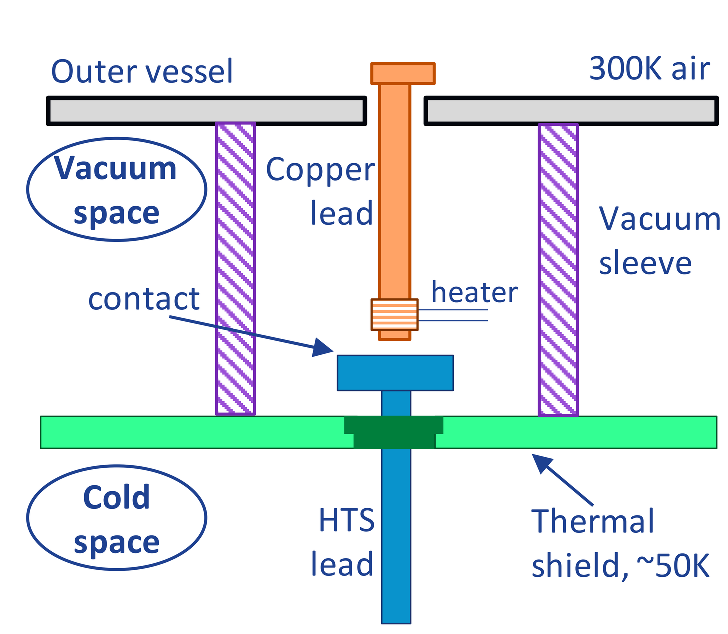

Figure 5. Heaters on leads for melting ice

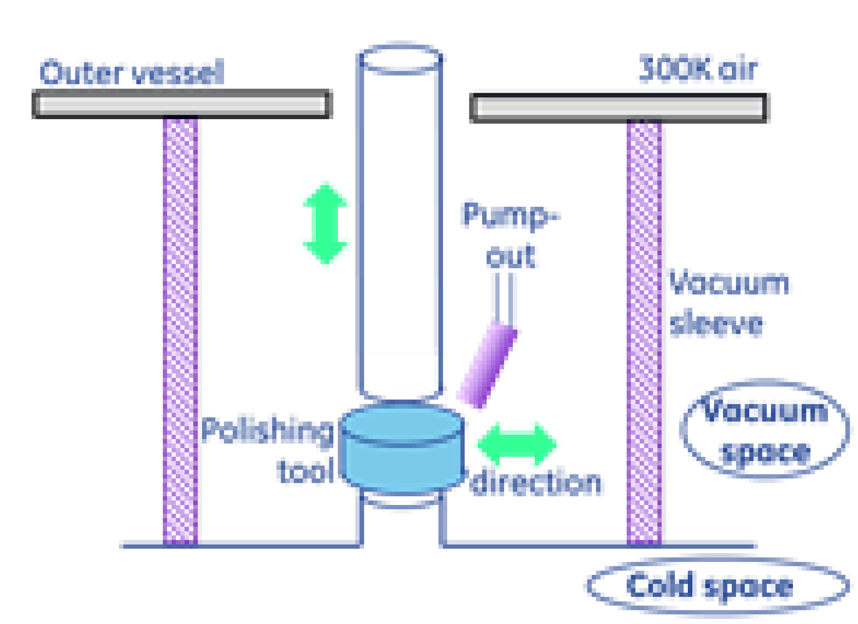

Figure 6. Surface polish tool.

5. Conclusion

Current reset arrangements with redundancy for reliability in superconducting magnets were discussed. A flux pump is also discussed with improved operational processes for reduced heat load and increased switch stability. Options RHCL were evaluated, with heaters on the lead contacts and a surface polishing device for improving the lead performance over time.